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U. S. Department of Commerce
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Technology Administration
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MULTI-FUNCTION SENSING FOR CYBERNETIC BUILDING SYSTEMS

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INTRODUCTION

Building control companies, equipment and system manufacturers, energy providers, utilities, and design engineers are under increasing pressure to improve performance and reduce costs by developing building systems that integrate more services, including energy management, fire and security, environmental control and people movement. How these systems communicate, interact, share information, make decisions, and perform in a synergistic and reliable manner is the subject of a large effort at the National Institute of Standards and Technology (NIST) in Cybernetic Building Systems (CBS). A portion of the research is focused on (1) the relationship between the signals from commercially available gas, particle and temperature sensors and the actual thermodynamic state of the room, (2) development of open protocols for the exchange of information among different sensors and building systems, and (3) aiding the fire brigade's attack strategy by effectively displaying the status of a fire on a smart panel capable of suggesting how the fire may evolve. This paper describes recent progress on the first topic (environment sensing), and introduces the third (the smart fire panel). A companion paper by Bushby[15] at this 15th United States/Japan Natural Resources (UJNR) Panel on Fire Research Safety deals with topic (2), information exchange.

BUILDING ENVIRONMENT SENSING

The objective of this effort is to permit fire and indoor air quality (IAQ) sensor designers to demonstrate the feasibility of new concepts, to provide the critical link between sensor input and output required for meaningful numerical simulations, and to improve the reliability and performance of fire detection and IAQ control systems. Increasing the number of sensors in a detector is one way to improve system flexibility, provide earlier warning, provide redundancy, and enhance discrimination of nuisance sources[1-4]. Multiple criteria algorithms that consider combinations of threshold values, rate of rise of signals, and statistical characteristics of signals recently have been employed and have begun to appear in commercial products. Typically, these detectors are certified ("listed") via the standard test protocols developed for single-sensor detectors which include full-scale room fire tests in EN 54 part 9[5], and UL 268[6]. The enhanced benefits of multi-sensor, multi-criteria detectors over single-sensor detectors are not completely established by such tests. (Little work has been done even to define the applications of IAQ sensing or to the manner in which IAQ sensing should be combined with fire sensing.) A multi-sensor, multi-criteria fire detector may meet the detection time limits for most or all test fires in EN 54 part 9, implying that such a detector is appropriate for various applications. However, the detector could utilize complex and proprietary algorithms that would make estimation of detector performance in other scenarios difficult. In addition, individual sensor response to nuisance sources combined with algorithm processing may enhance or degrade false alarm susceptibility.

The fire emulator/detector evaluator (FE/DE)[7] is being developed at NIST to address issues concerning multi-sensor, multi-criteria detectors and combination IAQ/fire sensors. The FE/DE, shown schematically in Fig. 1, provides a controlled environment where sensors can be exposed to fire signatures, indoor air pollutants, and nuisance sources. Increasing temperature, changing velocity, and varying particulate and chemical species concentrations at the detector location are some of the variables controlled. The device has been used to evaluate the smoke entry lag effects of detectors at low to moderate flows[8]. Analog output detectors (detectors that can provide a continuous output signal to a computer) were exposed to square wave changes in smoke concentration at various fixed velocities and fixed ambient temperature. A two parameter model was developed to capture the time lag which was observed to be substantial at low flow velocities (< 0.05 m/s). The exposure of sensors to nuisance aerosol exposures is also underway[9].

Environmental signatures at the sensor location to be emulated in the FE/DE can come from full-scale experiments or numerical simulations of the smoke, gas, and heat transport from a fire or other source. Cleary et al.[10] varied the velocity, temperature, and smoke concentration over time in the FE/DE to demonstrate that a test fire exposure can be emulated in a repeatable manner, and that a multi-sensor, multi-criteria detector's response can be evaluated. Examples of their results are reproduced here.

Test fire number four (TF 4) from EN54 part 9 is a polyurethane foam fire consisting of three mats (50 cm by 50 cm by 2 cm thick stacked on top of one another) that exhibits a peak heat release rate of approximately 50 kW and produces a large amount of smoke[11]. While smoke and temperature values at a standard detector location have been reported in the literature, velocity measurements are not available[11,12]. To overcome this deficiency, computational fluid dynamics calculations of the fire were conducted to predict the velocity profile at the detector location, as well as the time-varying temperature[10]. Figure 2 shows the simulated velocity profile and the duct velocity in the FE/DE. (In order to maintain an increasing smoke concentration, the peak duct velocity was intentionally reduced in order to lower the smoke dilution factor.) Also shown in Fig. 2 is the simulated temperature profile, the full-scale room measurement, and the profile reproduced in the FE/DE. Near the end of the test, the full-scale room temperature starts to fall as the fire dies out, whereas the temperature profile reproduced in the FE/DE does not fall because of the slow cool down of the heating elements.

The FE/DE light extinction measurements[10] were found to be almost a factor of two lower than values produced in full-scale room tests. This discrepancy was attributed partially to the different light sources used. (Dobbins *et al.*[13] reported specific extinction measurements of crude oil pool fire smoke to be 7.8 m^2/g for light at 630 nm, the wavelength of the extinction measurement in the FE/DE, and 5.1 m^2/g at a wavelength of 1000 nm, close to the wavelength used in the EN54 test) In addition, the FE/DE optical density is limited by the smoke produced in the propene burner. A redesign of the burner damper controls is planned to permit higher smoke concentrations at the test section.

The multi-sensor detectors used in the study were commercially available units that contained individual photo-electric light scattering, ionization, and heat sensors. The output for each sensor was transmitted at about 2 s intervals. The particle sensors were found to be linear

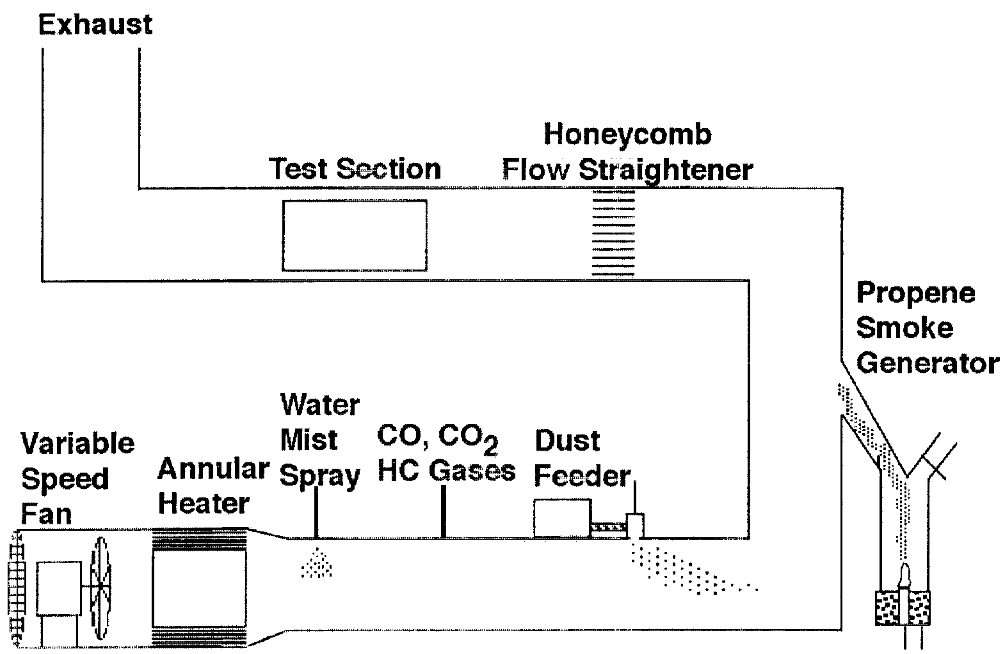

Figure 1. Schematic of the Fire Emulator/Detector Evaluator (FE/DE).

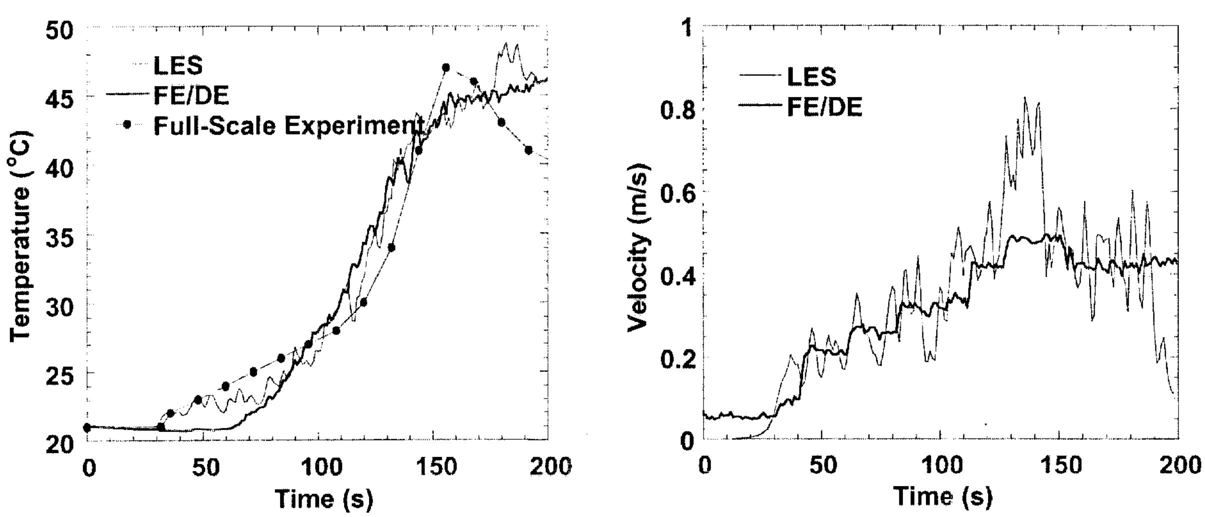

Figure 2. Temperature and velocity profiles; FE/DE compared to large-eddy simulation (LES) and full-scale room test (temperature only). See reference 10 for discussion of uncertainty.

functions of optical density for smoke produced by the propene burner, while the heat sensor output was proportional to the temperature in the test section.

Figures 3 shows the detector output along with the extinction and temperature values recorded at the test section plotted vs. time for a typical test. The photo-electric and ionization sensor outputs closely follow the optical density measured outside the detector. In this scenario the velocity profile quickly rises to over 0.2 m/s where little smoke entry time lag is expected. The output of the photo-electric sensor and the ionization sensor are similar in shape and magnitude. There is a noticeable time lag associated with the thermistor used as the heat sensor compared to the thermocouple measurement, indicating a significant difference in thermal inertia between the two devices.

The left plot in Fig. 4 shows the test section temperature versus time for each of six experiments, T1-T6. Satisfactory repeatability is indicated by the narrow spread among the curves. The optical density (a 15 point running average was used to smooth the curves) is shown at the right of Fig. 4. Some run-to-run variation in the optical density should be reduced by the new smoke control strategy.

The detector used in this study employed a proprietary algorithm to combine the signals from the individual sensors with an alarm threshold based on multiple criteria. The time-to-alarm for the six different tests is indicated in Fig. 4. The values ranged from 165 s to 181 s, a window of time narrow enough to discriminate between the performance of different designs.

INVERSE FIRE MODEL AND DEVELOPMENT OF A SMART FIRE PANEL

Fire fighting in large structures such as apartment, office, and commercial buildings is complicated by lack of information about fire fighters inside the building and the extent of the fire within the structure. Most buildings of this type have installed fire detection systems that supply limited information from fire detectors in the building to a fire alarm panel generally located in the lobby of the building and to a fire command center -- a room from which fire department operations in the building can be controlled. The information available today and likely to be available in the near future in new buildings with advanced sensors can be used to improve the fire service response and improve the safety of the fire fighting effort.

In cooperation with fire service organizations, major fire departments and the fire alarm industry, NIST is examining the capabilities to display and use information available today in buildings. Through virtual demonstrations NIST will provide insight into the capabilities that could be developed and widely disseminated through a new standard interface. In part through continued focus group interactions with the fire fighters and their organizations, a plan will be developed for the technology needed to make fire system and building information as useful as possible for efficient and safe fire fighter operations.

In addition to evaluating new sensors and detection systems in the FE/DE as described above, a means to interpret data from multiple sensors over time is required. The objective is to identify

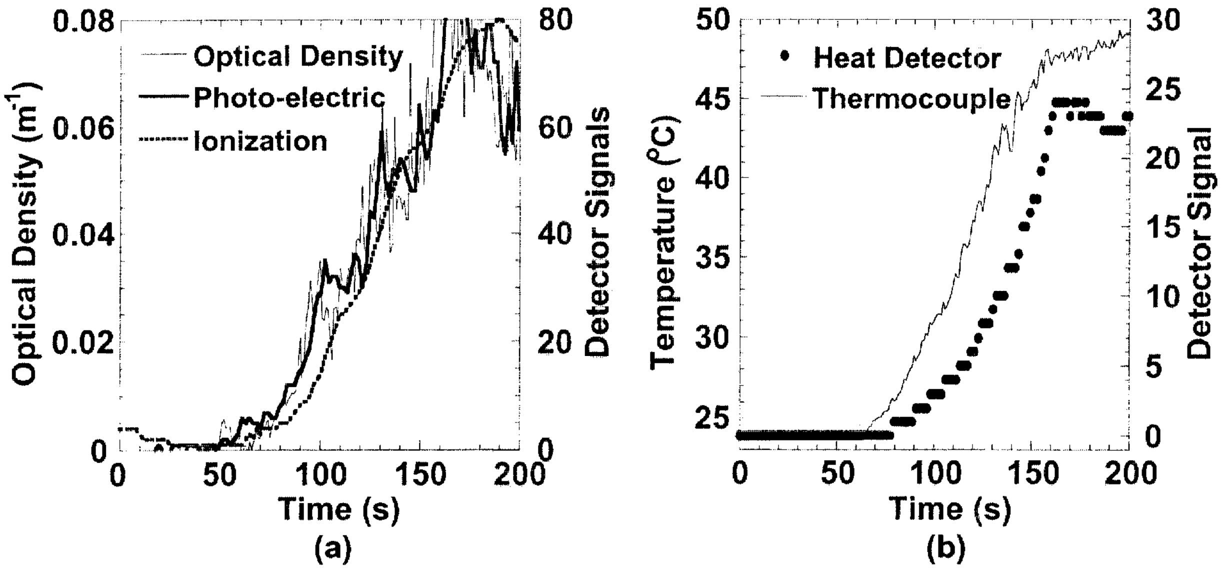

Figure 3. Detector response to emulated TF 4 conditions. See reference 10 for discussion of uncertainty.

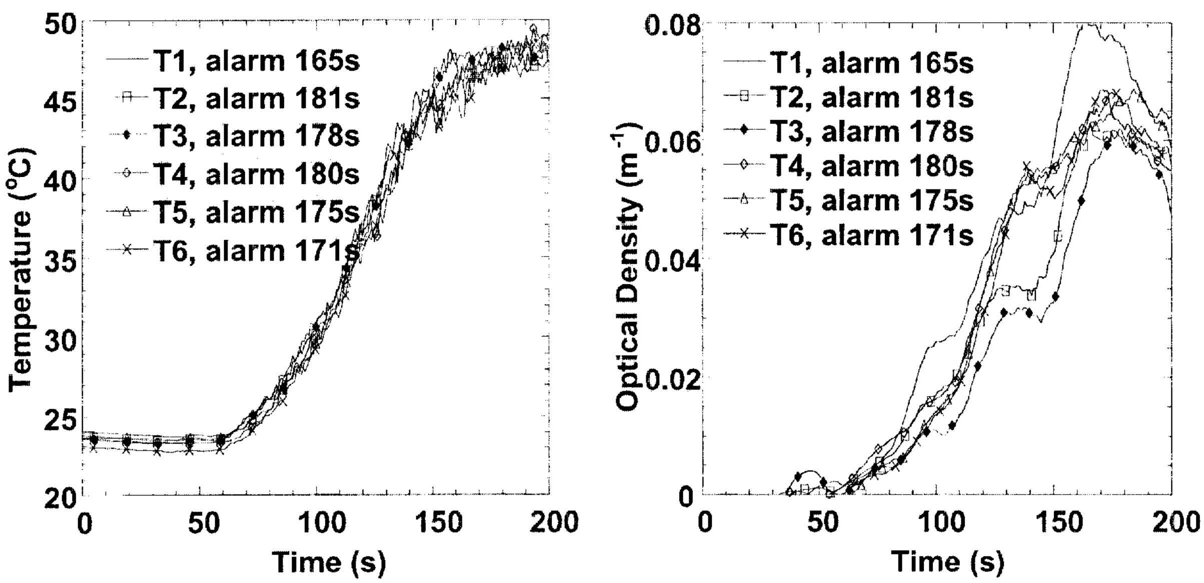

Figure 4. Smoothed temperature and optical density data vs. time using FE/DE; six duplicate tests. Range of times to alarm is from 165 s to 181 s. See reference 10 for discussion of uncertainty.

if a fire is present in the building or not, and if present, where it is located, how fast it is growing, and which regions of the building are likely to be hazardous to the occupants or fire fighters. An inverse fire model is being developed at NIST for this purpose. Version 1 of the model will use the output from smoke and heat detectors (or a data file simulating detector signals) to determine the heat release rate, and the temperature and depth of the smoke layer in each affected room as a function of time. A second version is envisioned that will include additional fire and detection system phenomena such as signals from CO/CO_2 sensors, heat and smoke transport through the building ventilation system, prediction of flashover, window breakage, wall failure, ceiling jets in other rooms, etc. The decision concerning which of the additional fire phenomena to include will be based on the impact that the inclusion of each fire phenomena will have on hazard analysis and the experimental basis available for model testing. The model will be tested in part using the Virtual Cybernetic Building Testbed (VCBT). The VCBT is a computer simulated building environment that includes ventilation systems, fire panels, and heating/cooling systems to mimic the operation of an actual building.

Many fire departments report that they seldom use features that are provided by the current generation of fire panels because of the multitude of system interfaces that exist. Displays and controls are not consistent and there is no time to study the manuals. NIST, through a cooperative research project with the National Electrical Manufacturer's Association and major alarm panel manufacturers, is developing the technical basis for establishing a standard interface.[14]

The first step is to determine the information needs of the fire service. In a series of meetings, participants were asked what they want to know, when do they need to know it, and how do they want the information presented. The answers were categorized by needs at dispatch, upon arrival at the scene, and during the incident. The information on functions and system components would be displayed via icons, standardized in the National Fire Alarm Code (NFPA 72), but with the freedom to use graphical displays over hard buttons, labels on hard buttons with lights, or on touch screens. The initial set of icons proposed is based upon current practice and NFPA 170. The icons need to represent three states: if the function is present, present and not active, present and active. Caution was suggested regarding the use of color for these states with the knowledge that some fire fighters are colorblind.

A prototype panel is being assembled to capture the ideas discussed at these meetings. It will incorporate features and arrangements that would be part of any proposed standard and demonstrate optional approaches. An example display is shown in Fig. 5. Two other windows can be addressed which display a plan view of the floor of origin and a building elevation view.

Information available for display at the incident will depend upon the type and extent of fire protection system installed, and the sophistication of the building control systems. A new fire panel designed using the guidance provided by this research effort should be useful for older zoned systems as well as for more modern point addressable devices, and adaptable to exploit whatever new building controls and sensors are on the horizon. Eventually it is anticipated that inverse fire models will be able to digest this abundance of data and make highly reliable assessments of the building conditions and fire fighting options.

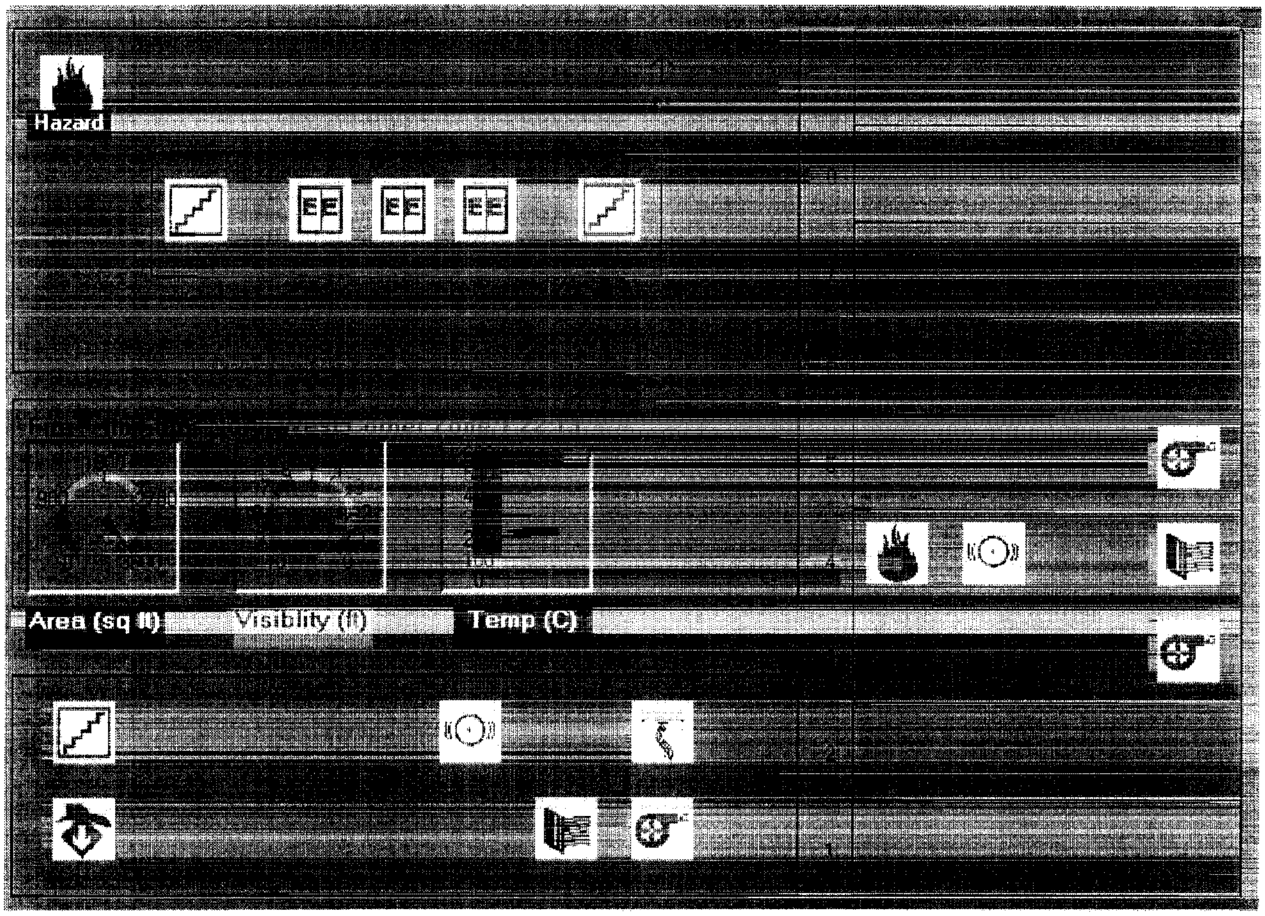

Figure 5. Prototype of a standard fire service interface in a nine story building. Refer to Bukowski[14] for a definition of symbols.

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